EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — BEAMS DEPARTMENT

CERN-BE-2009-034 RF

ORTHOGONAL COUPLING IN CAVITY BPM WITH SLOTS

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Abstract

XFELs require high precision orbit control in their long undulator sections. Due to the pulsed operation of drive linacs the high precision has to be reached by single bunch measurements. So far only cavity BPMs achieve the required performance and will be used at the European XFEL, one between each of the up to 116 undulators. Coupling between the orthogonal planes limits the performance of beam position measurements. A first prototype build at DESY shows a coupling between orthogonal planes of about -20 dB, but the requirement is lower than -40 dB (1%). The next generation cavity BPM was build with tighter tolerances and mechanical changes, the orthogonal coupling is measured to be lower than -43 dB. This report discusses the various observations, measurements and improvements which were done.

Presented at the 9th Europeran Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC),
held in Basel, Switzerland, 25-27 May 2009

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XFELs require high precision orbit control in their long undulator sections. Due to the pulsed operation of drive linacs the high precision has to be reached by single bunch measurements. So far only cavity BPMs achieve the required performance and will be used at the European XFEL, one between each of the up to 116 undulators [1]. Coupling between the orthogonal planes limits the performance of beam position measurements. A first prototype build at DESY shows a coupling between orthogonal planes of about -20 dB, but the requirement is lower than -40 dB (1%). The next generation cavity BPM was build with tighter tolerances and mechanical changes, the orthogonal coupling is measured to be lower than -43 dB. This report discusses the various observations, measurements and improvements which were done.

INTRODUCTION

A cavity BPM consists of a coaxial dipole resonator with four symmetric arranged slots and a reference resonator, see Fig. 1. A charged particle beam excites electromagnetic fields. Antennas in the slots and the reference resonator observe a voltage. The signal used from the dipole resonator is the TM_{11} mode (the dipole mode is spatial filtered due to the slots), which is proportional to the beam offset times charge. Charge and phase normalization are done with the signal from the reference resonator (TM_{01} mode which is proportional only to the charge), see Fig. 2, such that the beam position is observed. The phase relation between dipole and reference resonator is used to determine the sign of the displacement.

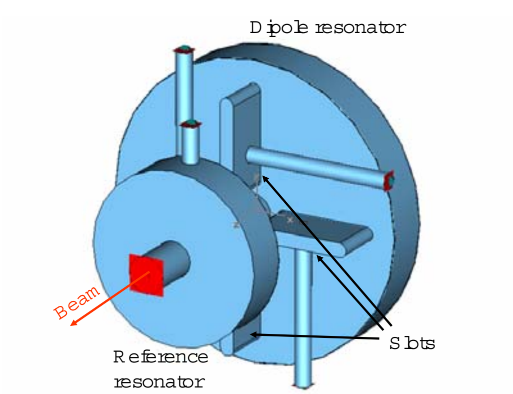

Figure 1: Design view of a cavity BPM, here only the vacuum parts are shown.

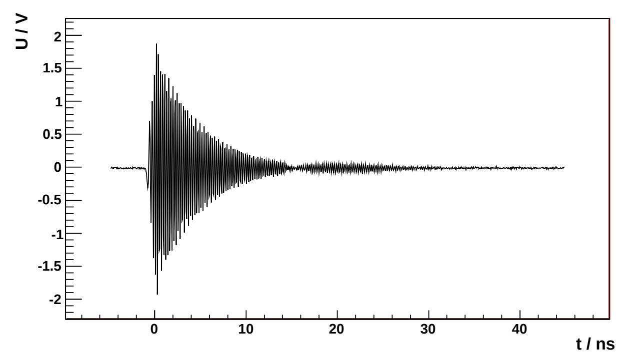

Figure 2: Time domain response signal from reference resonator with visible reflexion after about 14 ns.

Both transverse beam displacements are measured by using two orthogonal feedthroughs (ports) of the dipole resonator, the other two ports are terminated by 50 Ω loads. When the beam is only shifted in one direction with respect to the electromagnetic axis of the BPM only one port should show an offset. With a coupling of both planes the other port will give a signal too, see Fig. 3. If the resulting coupling is larger than requested this limits the BPM performance.

This paper shows the investigation of the coupling for two prototypes (one of the first and one of the second generation) with two methods. The reason of the coupling is evaluated and possible improvements are named.

FIRST CAVITY BPM GENERATION

Three prototypes have been produced at DESY. The design originally developed at SPring-8 [2] was changed according to the boundary conditions of the European XFEL with a resonance frequency of 4.4 GHz. One prototype was installed at FLASH in 2008, see Fig. 4. The BPM can be moved in both transverse directions by stepper motors. The ports are connected with 1.5 m long cables (H&S SUCOFORM SM141) followed with 120 m long cables (RFS LCF 78-50JA 7/8” CELLFLEX) each. The signals are taken with an oscilloscope, 20 GSamples/s. In Fig. 3 the signal from the orthogonal port shows a different decay time compared to the *correct* port. This leads to the assumption that the loaded quality factor is increased. The signals shown in Fig. 2 and Fig. 3 top indicates a reflexion

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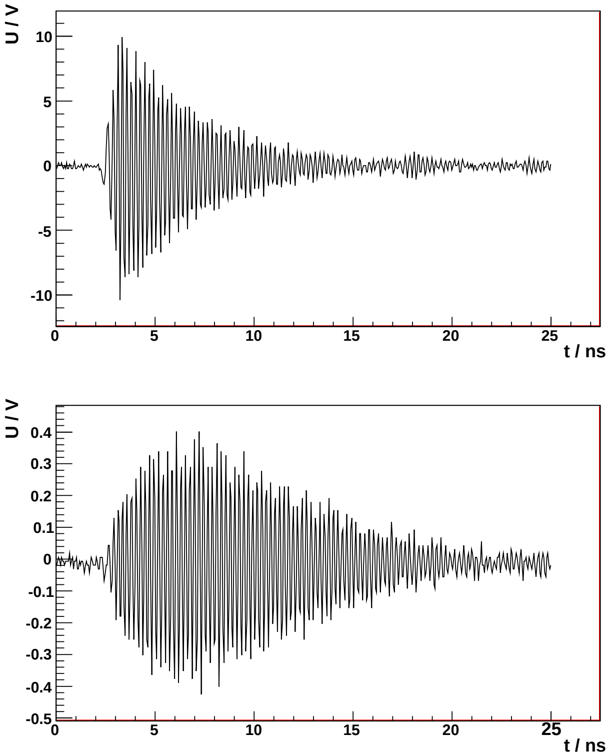

Figure 3: Time domain response signal of dipole resonator. Top: with beam offset of 1.08 mm, bottom: from the orthogonal port. Note the different vertical scales.

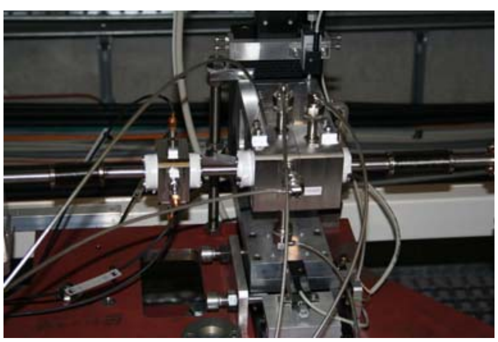

Figure 4: Photo of the installed cavity BPM first generation at FLASH.

after about 14 ns which could influence the quality factor. The reflexion is caused by the interface between the 1.5 m and 120 m long cables. The Fourier transformed signal of Fig. 3 shown in Fig. 5 gives a smaller bandwidth of the coupled signal at the same frequency, an indication of a larger quality factor too.

To estimate the amount of coupling the maximum level at the resonance frequency is taken as a function of beam offset in one transverse direction, see Fig. 6. With increasing offset both ports show an increasing level, the coupling is about -20 dB (10%) which is above the requirement of 1%. Therefore this signal influences the performance of

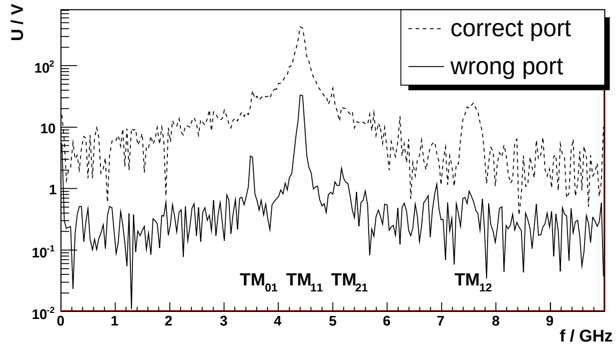

Figure 5: Fourier transformation of signals shown in Fig. 3. Monopole mode leakage at 3.5 GHz is observed too. The first quadrupole mode (TM_{21}) at 5.2 GHz and the second dipole mode (TM_{12}) at 7.6 GHz are visible.

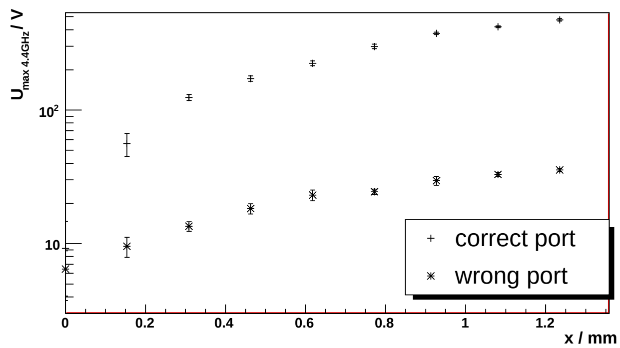

Figure 6: Maximum level at dipole resonance frequency as a function of beam offset for both ports. Error bars are the standard deviation of several measurements.

the BPM.

The transmission of the orthogonal ports of the BPM was measured with a network analyzer without long cables shown in Fig. 7. Here one can see the same level of coupling.

To derive the reason of the coupling CST simulations [3] are performed with shifting non-cylinder-symmetric components of the BPM. An agreement of the transmission measurement was found (see Fig. 7) by shifting one slot by 0.09 mm with respect to his center position (the defined tolerance was ± 0.2 mm). The resonance frequency of the measured BPM was 4.408 GHz, therefore the measured data are shifted, which is within the accepted tolerance of ± 10 MHz. The dipole mode is on the shoulder of the first quadrupole mode therefore the baseline of the transmission is increasing with frequency in Fig.7. But this quadrupole mode has only negligible influence to the measured offset position.

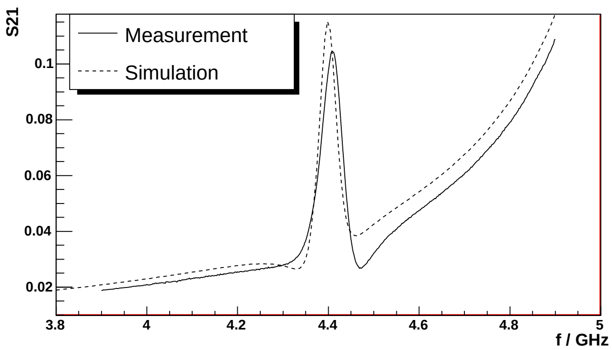

Figure 7: Transmission between orthogonal ports of at FLASH installed BPM without long cables: measurement and simulation (shift of slot position: 0.09 mm).

SECOND CAVITY BPM GENERATION

The next prototypes have been produced with a resonance frequency of 3.3 GHz. The lower resonance frequency was chosen to be able to design cavity BPM with larger beam tube and the same performance like the undulator cavity BPM. This gives the possibility to use the same electronics at different positions of the beam distribution system. The mechanical tolerance of the slot position is tightened to ± 0.05 mm and the vacuum tube connection of the slots are closed (compared to the origin design [2]). Due to the lower resonance frequency the baseline transmission is increased. The closed vacuum tube connection decreases the baseline transmission again, shown in Fig. 8. A small peak is observed at the resonance frequency, but not significant like in Fig. 7, note the different scales. One BPM of the second generation was used to replace the first generation prototype in FLASH, see Fig. 9. The same measurement as a function of beam offset was done, see Fig. 10. The orthogonal port gives a small peak at the resonance frequency but it does not increase with larger beam offset (a larger beam offset range was used compared to Fig. 6). Therefore from this data one can estimate an upper limit of the coupling of -43 dB.

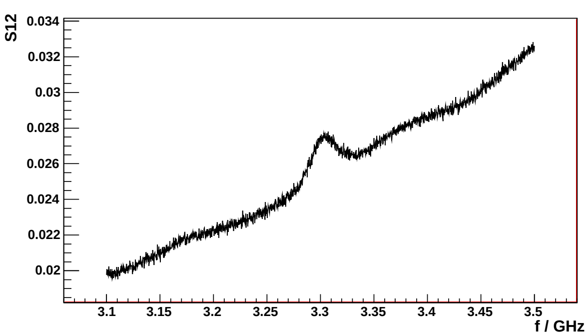

Figure 8: Measured transmission of the second generation cavity BPM between orthogonal ports.

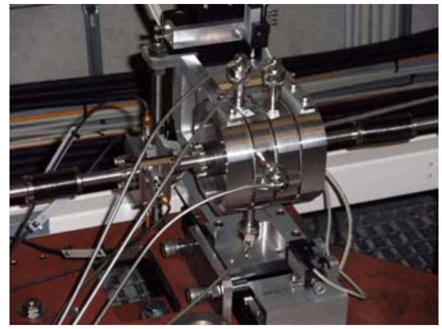

Figure 9: Photo of the installed cavity BPM second generation at FLASH.

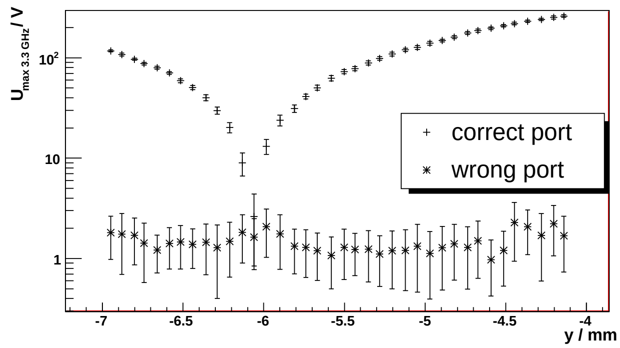

Figure 10: Maximum level at dipole resonance frequency of second prototype as a function of vertical mover position for both ports. Error bars are the standard deviation of several measurements. BPM center is at about -6.08 mm.

SUMMARY

The first cavity BPM generation for the European XFEL showed a coupling of orthogonal port signals measured with beam and verified with transmission measurement of -20 dB. The reason was a too loose tolerance of the position of the slots. By tightening the tolerance the coupling is reduced and measured to be lower than -43 dB. It turns out that coupling is sensitive to geometric errors of a cavity BPM. Thus it can be used as one measure in the quality control process of the series.

ACKNOWLEDGMENT

The author thanks Thomas Traber for his support to the measurement with the Network Analyzer.

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